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TEST REPORT

Increased Noise in Silicon JFETS Following 63-MeV Proton Irradiation

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1. SUMMARY

Irradiation of JFETs to 62.5-MeV protons resulted in increases in the JFETs' noise spectra. Although all the JFETs were processed from a single silicon wafer, they are not all affected identically by the radiation. The noise in some of the JFETs increased gradually with proton fluence, but then decreased during an annealing period following the final exposure. In other JFETs the noise increased discontinuously at a relatively low exposure level, and additional exposures caused no further increases in noise. Furthermore, during the annealing period there was no reduction in the noise. Two of the JFETs exhibited characteristics of both types of responses to radiation exposure, i.e., there was a discontinuous increase in the noise spectra with proton fluence followed by saturation, but some recovery did occur during the annealing period. The origins of these different responses are currently under investigation.

2. BACKGROUND

The AstroE2 observatory is designed to detect X-rays from deep space using arrays of Si JFETs operating at 130^o K. Because the X-rays are very weak, they deposit small amounts of energy in the JFETs, which must have very low noise levels in order to be able to detect the weak X-ray signals. Noise levels should remain low during the entire mission, even in the presence of particle radiation that can produce displacement damage in the JFETs. To test whether the noise levels in the JFETs increase following exposure to protons, we exposed the detector arrays to a beam of protons with nominal energy of 62.5 MeV.

3. DEVICES

All the JFETs were manufactured by Interfet from the same silicon wafer. Their ID number was SNJ14AL16.

4. EXPERIMENTAL SETUP

The detector consisted of an array of 18 JFETs. The array was mounted in a dewar and cooled with liquid nitrogen to between 120^{o}K and 130^{o}K. Two JFETs were not functional, so only 16 were tested. The dewar was positioned in front of the accelerator's exit port such that the proton beam passed through a thin (3/16?) aluminum window. Inside the dewar was an aluminum box containing the detector array. The walls of the box were made of aluminum 30 mils thick. The JFETs themselves were mounted on cold-fired aluminum oxide substrates 50 mils thick. There were two substrates, each containing 9 JFETs. The two substrates were placed so that the JFETs faced each other with a 10 mil piece of aluminum between them. Together, the detector configuration had the appearance of a "sandwich" as shown in figure 1.

To reach the JFET array closest to the exit port, the protons travelled through a combined aluminum thickness of 215.5 mils and 50 mils of Al_2O_3. To reach the second array the protons travelled through an additional layer of aluminum 10 mils thick. After passing through the 215.5 mils of Al and the 50 mils of Al_2O_3, the proton energy is reduced from 62.5 MeV to 47 MeV. The additional 10 mils of Al have a negligible effect on the protons' energy. JFETs numbered 1 through 8 are closest to the accelerator's exit port.

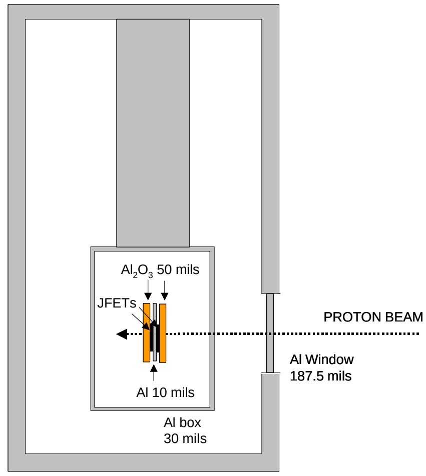

Figure 1. Schematic of test assembly showing dewar with an aluminum window. Inside the dewar is the aluminum box containing the two JFET arrays.

The configuration used for making the noise measurements is shown in Figure 2. The source is tied to 5 V and the gate is grounded. A mechanical switching box allows each one of the JFETs to be connected separately to the voltage-sensitive amplifier which has a gain of 20 K and has a noise level of 1 nV/?Hz. The input of the amplifier is also connected to a voltage of –7 V through a resistor of 121 K? . Under these conditions the current through the JFET is 66 ?A. The noise at the input of the amplifier is dominated by the noise in the JFET. The output of the voltage-sensitive amplifier is connected to a spectrum analyzer (HP35665A). All measurements were made at a temperature of 130^{o} K.

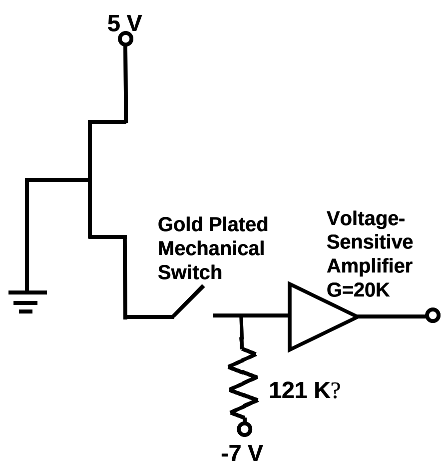

Figure 2. Configuration used for measuring the noise levels in the JFETs. The output of the voltage-sensitive amplifier is connected to a spectrum analyzer (HP35665A) which displays the noise level as a function of frequency.

Measurements of the noise spectra were taken prior to radiation exposure and then following each exposure. The JFETs were irradiated with their gates grounded to the dewar and the other connections floating. Immediately after irradiation, the dewar was removed from in front of the accelerator port and transported to the experiment control room where the noise measurements were performed. Noise measurements were done for each JFET, one at a time, by connecting drain of each JFET to the voltage-sensitive amplifier through a switching box in which the individual contacts were gold plated. The complete set of measurements required about 2.5 hours. The proton exposure levels are given in Table 1. Each exposure required about a minute. Noise measurements were made after the final exposure and then following two annealing periods, the first about 12 hours and the second about 30 hours after the final exposure. These two measurements were done to determine whether there was any annealing of the damage with time.

Table I
Proton Dose and Fluence for Each Run

Run #	Dose Krad(Si)	Fluence (cm^{-2})
1	0.5	$3.88x10^{9}$
2	1.0	$7.75x10^{9}$
3	2.0	$1.55x10^{10}$
4	3.0	$2.33x10^{10}$
5	4.0	$3.10x10^{10}$
6	5.0	$3.88x10^{10}$

5. Results

Of the 16 devices tested, 8 showed a steady increase in the noise levels followed by a decrease during the annealing phase. A further 6 devices showed a sudden large increase in the noise level, and then no further increases with additional exposure and also no changes during the annealing phase. Two devices seemed to straddle the two categories because there was a sudden discontinuous increase in the noise spectra following a certain dose level, but the magnitude of the noise did decrease during the annealing period. Table II shows which devices fell into which category.

Table II
Response Categories for JFETs following Proton Irradiation

JFETs Exhibiting Gradual Increase in Noise Spectra with Proton Fluence followed by Decrease During Annealing	JFETs Exhibiting Discontinuous Increase in Noise Spectra with Proton Fluence with No Decrease During Annealing	JFETs Exhibiting Discontinuous Increase in Noise Spectra with Proton Fluence and a Decrease During Annealing
#1	#2	#11
#3	#5	#13
#4	#8	
#6	#10	
#7	#15	
#12	#16	
#14		
#17		

Figure 3 shows the noise spectra for JFET #1. The noise levels displayed by the spectrum analyzer is divided by 20,000 because the signal from the JFET was amplified by 20,000. The legend in the graph lists the occasions on which the noise spectra were obtained. Two measurements were taken at GSFC prior to shipping the parts to the accelerator and three measurements were done following arrival at the accelerator. In this way it was possible to determine whether there was any increase in the noise due to shipping. One noise spectrum was obtained following each exposure level.

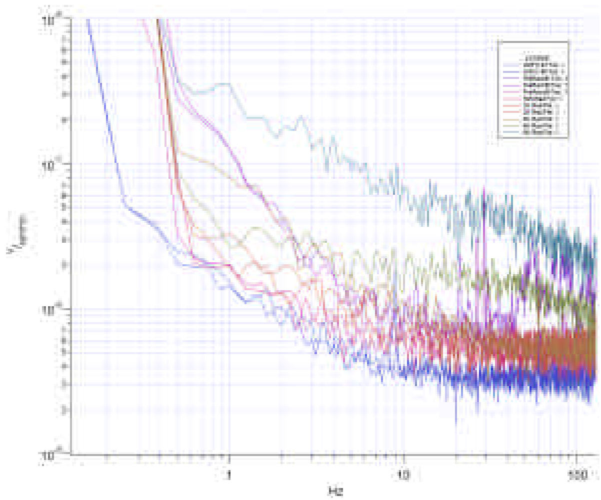

Figure 3. Noise spectra for JFET #1 measured twice at GSFC before shipping, then measured three times at the accelerator facility prior to irradiation, and then following each exposure. The noise level is along the y-axis and is measured in Volts/?Hz. The frequency is along the x-axis. The graph shows that the noise increases with increasing proton dose (fluence).

Figure 4 shows the noise spectra for JFET #16. It is clear that, following a dose of 1 krad(Si), there is a large increase in the noise level and that there are no further increases in the noise spectra following additional exposures to the proton beam.

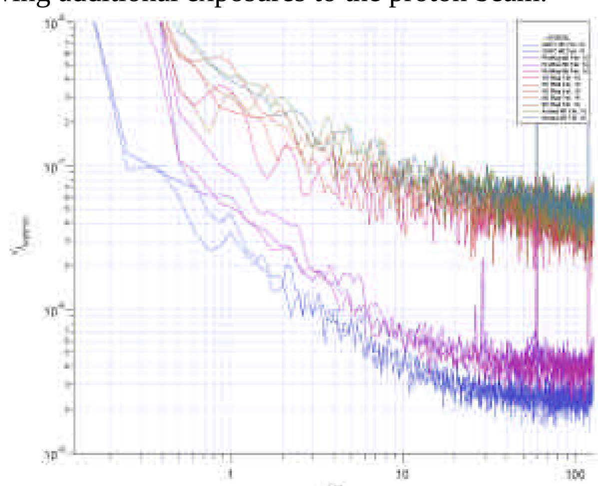

Figure 4. Noise spectra for JFET #16 showing the sudden increase in noise following a TID of 1 krad(Si) and then no further increases with dose.

The effects of annealing were also investigated by doing noise measurements after various intervals of time following irradiation. The first measurement was done about 12 hours after completion of the irradiation during which time the device was kept at about 120 K. Figure 5 shows the noise spectra for the JFET #1. It is clear that there is some recovery in the noise, particularly at low frequencies. Figure 6 shows that there is very little recovery in JFET #16 during the annealing process.

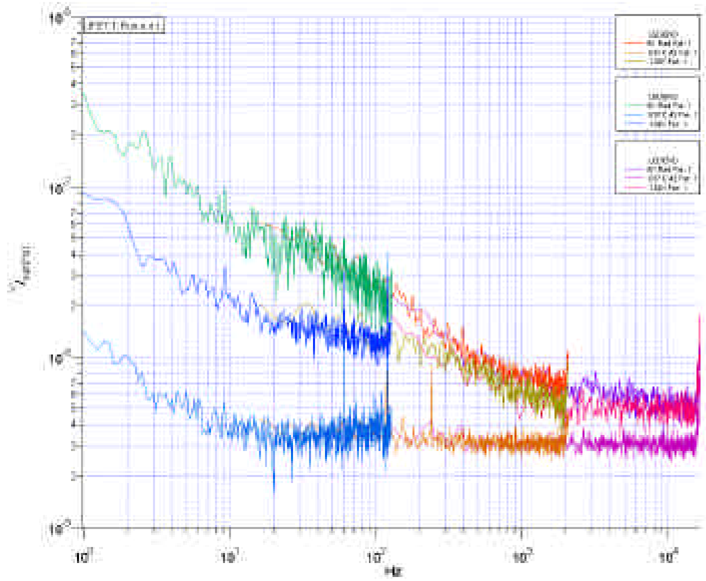

Figure 5. Comparison of noise spectra for JFET #1. The lowest spectrum was taken prior to irradiation, the top spectrum after a fluence of $3.88 \times 10^{10}/cm^2$, and the middle spectrum after annealing at 135 K for 30 hours. The results clearly show some recovery during the annealing phase.

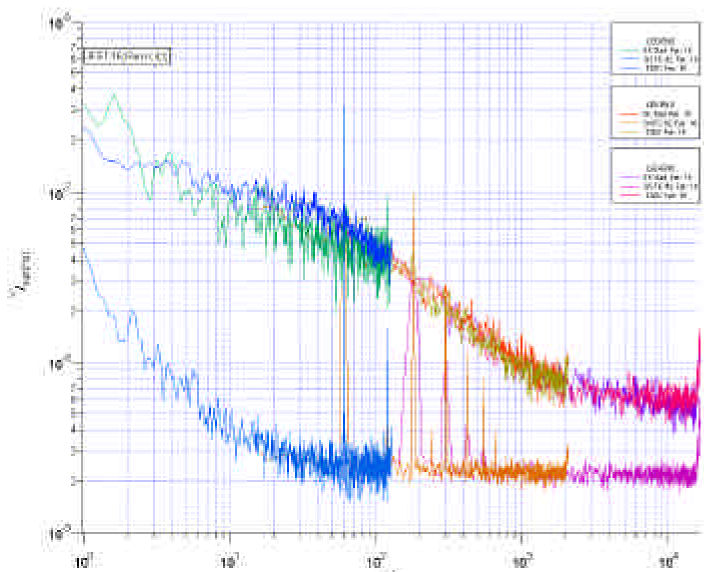

Figure 6. Comparison of noise spectra for JFET #16. The lowest spectrum was taken prior to irradiation, the top spectrum after a fluence of $3.88 \times 10^{10}/cm^2$, and the middle spectrum after annealing at 135 K for 30 hours. The results clearly show very little recovery during the annealing phase.

6. Summary and Conclusions

As a result of proton irradiation, JFETs manufactured by Interfet exhibited increased noise levels. In some of the JFETs the noise spectra increased monotonically with proton fluence (dose) and some of the radiation induced noise decreased during an annealing period. In other devices the noise increased discontinuously with proton fluence, saturated at a very low dose (1 krad(Si)) and displayed very little recovery during the annealing period. Two devices appeared to have characteristics of both types of damage, i.e., a discontinuous increase in noise following by some reduction during the annealing period. Further investigations into this causes of this behavior are planned.